

## THERMAL TRANSFER INTERFACE SYSTEM AND METHODS

### BACKGROUND OF THE INVENTION

[0001] Electronic systems often incorporate a semiconductor package (e.g., including a semiconductor die) that generates significant thermal energy. System designers spend considerable effort to provide sufficient heat dissipation capability in such systems by providing a thermally conductive path from the package to a heat sink. A heat sink may for example be a ventilated conductive plate or an active device such as a thermoelectric cooler.

[0002] Certain difficulties arise when these electronic systems utilize multiple dies and other heat-generating devices. More particularly, each die and device must have its own heat dissipation capability; this for example complicates system design by requiring that there is adequate ventilation and/or thermally conductive paths and heat sinks for the entire system. Such ventilation, thermal paths and heat sinks increase cost and complexity, among other negative factors.

[0003] Certain difficulties also arise in multiple die electrical systems because of mechanical tolerance build-up. That is, the physical mounting of multiple dies on a printed circuit board (PCB), for example, results in some minute misalignment between reference surfaces intended to be co-aligned. Accordingly, any attempt to use a common heat sink must also accommodate the tolerance build-up to ensure appropriate thermal transfer across the physical interface. Tolerance build-up may for example occur due to the soldering that couples the dies to the PCB, and/or due to manufacturing inconsistencies in the rigid covers or "lids" which sometimes cover individual dies. In any event, a thermal sink coupled to multiple dies should account for tolerance issues at the interface between the sink and the multiple dies in order to properly dissipate generated thermal energy. Designers of the prior art thus often over-compensate the thermal design to accommodate worst-case interface tolerance issues. Once again, this increases cost and complexity in the overall electrical system, among other negative factors.

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[0004] The invention provides certain features to advance the state of the art by providing, among other features, a thermal transfer interface system for dissipating heat from multiple dies in an electrical system. Other features of the invention will be apparent in the description which follows.

#### SUMMARY OF THE INVENTION

[0005] In one aspect, the invention provides a thermal transfer interface. A thermal spreader forms a plurality of passageways. A spring element couples with the spreader. A plurality of thermally conductive pins are included and arranged for movement along the passageways. Each of the pins has a head and a shaft moving with the spring element. At least part of the shaft is internal to the passageway; and it forms a gap with an internal surface of the passageway. The gap may be an air gap or filled with a thermally conductive material such as thermal grease. In operation, the pin heads collectively and macroscopically conform to an object to transfer heat from the object to the thermal spreader through the passageway gap formed between the heat sink and each of the plurality of pins. In one aspect, the spreader is a heat sink; for example the spreader is actively cooled by liquid or ventilated by air to dissipate heat from the pins. In another aspect, a separate heat sink couples with the spreader to dissipate the heat from the spreader. In still another aspect, the pins extend through the spreader so that they extend from the object through the spreader and into a cooling medium (e.g., air); the pins extending into the cooling medium act to dissipate heat and draw thermal energy from the spreader and/or object to the medium.

[0006] The spring element of one aspect forms a layer with a substantially planar face. One or more of the pin heads protrude from the face in a direction away from the spreader. In another aspect, one or more of the pin heads are substantially flush with the face. In yet another aspect, one or more of the pin heads are embedded within the spring element. Thermal grease or other conductive medium may assist in thermal heat transfer from the object to the pins and/or spring element.

[0007] In yet another aspect, the pin head is slightly smaller than the remainder of the pin shaft so that a pin shoulder is formed. A retaining element couples to the spreader to retain the pin shafts between the spreader and the retaining

element; the pins axially move along the passageway to couple with the object, as above, but the pin element will extend from the spreader only until the shoulder abuts the retaining element.

[0008] In another aspect, the passageways are sealed to form a cavity and the pin shafts seat in the passageways such that a filler medium pressurizes the pins to form the spring element. The filler medium may be air or a thermally conductive medium such as thermal grease. A small gap in the spreader may be included with one or more passageways to vent over-pressurization of the filler medium.

[0009] In still another aspect, the spring element includes a plurality of springs disposed between the spreader and the pin heads. In another aspect, the spring element includes a plurality of springs disposed within the passageways between the spreader and the pin shafts.

[0010] The pin shafts may be rectangularly shaped. The passageways have a similar though slightly larger shape to accommodate the pin shaft dimensions. As an alternative, the pin shafts are cylindrical in shape and the passageways are also cylindrical, though slightly larger in size to accommodate pin movement of the shaft therein.

[0011] The invention has particular advantages in dissipating heat from objects in the form of one or more semiconductor dies. In one aspect, a heat sink couples to the spreader. The heat sink may for example be an active thermoelectric cooler, a cooled thermally conductive element (e.g., a thermally conductive block cooled by liquid), or a passive thermally dissipating metal block.

[0012] The invention has further advantages in that it may be inverted depending upon desired application. That is, the invention of one aspect is a thermal interface: it transfers heat from one side to another irrespective of applied orientation.

[0013] In one aspect, the spring element is a thermally conductive sponge-like material. The spring element may be one or a combination of various forms of spring elements disclosed herein.

[0014] The invention also provides a method for transferring thermal energy from a body to a thermal spreader and/or heat sink, including the steps of: biasing a

plurality of pins against a surface of the object so that the plurality of pins contact with, and substantially conform to, a macroscopic surface of the object, and communicating thermal energy from the object through the pins to a thermal spreader forming a plurality of air gaps with the plurality of pins. The step of biasing a plurality of pins against a surface of an object may include the step of biasing the plurality of pins against a plurality of dies or semiconductor packages coupled with a printed circuit board or other electrical apparatus. The thermal spreader may act as the heat sink with the pins; or, in another aspect, a separate heat sink couples with the spreader.

[0015] The invention is next described further in connection with preferred embodiments, and it will become apparent that various additions, subtractions, and modifications can be made by those skilled in the art without departing from the scope of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0016] A more complete understanding of the invention may be obtained by reference to the drawings, in which:

[0017] FIG. 1 shows a cross-sectional side view of one thermal interface system constructed according to the invention;

[0018] FIG. 2 shows a top view of the system of FIG. 1;

[0019] FIG. 3 shows the system of FIG. 1 used to dissipate heat from a plurality of dies, in accord with one embodiment of the invention;

[0020] FIG. 4 shows a side view of another thermal interface system of the invention;

[0021] FIG. 5 shows a top view of one other thermal interface system of the invention;

[0022] FIG. 6 shows a cross-sectional view of the thermal interface system of FIG. 5;

[0023] FIG. 7 shows a perspective view of the thermal interface system of FIG. 5;

[0024] FIG. 8 shows a perspective view of several of the thermal interface systems of FIG. 5 operationally connected to dissipate heat from semiconductor packages of a printed circuit board;

[0025] FIG. 9 shows a cross-sectional view of the system of FIG. 8 coupled with two of the packages;

[0026] FIG. 10 shows another spring element configuration for biasing pins according to one thermal interface system of the invention; and

[0027] FIG. 11 shows another spring element configuration for biasing pins according to one thermal interface system of the invention.

#### DETAILED DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 shows a cross-sectional side view of one thermal interface system 10 of the invention. System 10 includes a plurality of thermally conductive pins 12 that interface with an object 14 to transfer heat from object 14 to a thermal spreader 16. A spring element 18 facilitates coupling between pins 12 and object 14 such that pins 12 collectively conform with a surface 14A of object 14, even if surface 14A is non-planar, such as shown. As used herein, each of pins 12 may for example be described with a head 12A and a shaft 12B, such as shown in FIG. 1. By way of operation, for those pins 12 that are in range of object 14, pin heads 12A are adjacent to, or in contact with object 14, while shafts 12B of pins 12 have at least some portion adjacent to, or in contact with thermal spreader 16. In one embodiment, pins 12 pass within a like plurality of passageways 16A of spreader 16. For purposes of illustration, only one passageway 16A is shown and identified in FIG. 1; pins 12 slide within passageways 16A to accommodate movement of pins 12, and/or element 18, in conformal contact with object 14.

[0029] FIG. 2 shows a top view of object 14 and system 10. For purposes of illustration, spring element 18 is transparently shown so as to clearly show the plurality of passageways 16A with pins 12. In operation, system 10 serves to dissipate heat from object 14 to spreader 16. Pins 12 are in thermal communication with object 14 when pins 12 (a) directly contact object 14, (b) couple to object 14 through a thermally conductive medium (e.g., thermal grease or a thermally

conductive spring element 18), and/or (c) are close to object 14 such that the air gap between pin heads 12A and object 14 does not substantially prohibit heat transfer. It is not necessary that every pin 12 thermally communicate with object 14. System 10 utilizes a plurality of pins that number in the tens, hundreds, thousands or millions; collectively these pins macroscopically conform to surface 14A of object 14 to transfer heat from object 14, through a plurality of pins 12 and to spreader 16.

[0030] Thermal spreader 16 may also form a heat sink to draw heat from object 14. Pins 12 may also form a heat sink; for example, by communicating air 19 across pins 12 extending through spreader 16, as shown, pins 12 are cooled to collectively function as a heat sink. Optionally, a separate heat sink 21 may couple to thermal spreader 16, as shown, to dissipate or assist in drawing heat from object 14.

[0031] Object 14 may for example be a semiconductor die or package, such as described in connection with FIG. 3. Spring element 18 may be replaced or augmented with different spring-like elements as described in more detail below.

[0032] FIG. 3 shows system 10 in another configuration, where the object is a plurality of objects 30A-30C. In one embodiment of the invention, objects 30A-30C are semiconductor packages and/or dies (collectively "dies" 30). As shown, objects 30 are beneath system 10, illustrating that system 10 may be configured in multiple orientations without departing from the scope of the invention; by way of example, system 10 may mount on top of dies 30 using its weight or other force to couple pins 12 to dies 30. Each of dies 30 is shown with a different physical size and with a different physical separation 32 from system 10, as compared with other dies 30, so as to illustrate that system 10 may accommodate physical non-uniformities and uneven surfaces of objects 30. Dies 30 may for example couple with a PCB 34 via solder or socket connections 36, as shown; solder or socket connections 36, and the manufacturing build-up tolerances of PCB 34 and dies 30, may cause the variations in separation differences 32 between the multiple dies and system 10, such as shown. Pins 12 axially move along direction 31, within passageways 16A and relative to thermal spreader 16 to accommodate conformal contact with object 30. As above,

spreader 16 and/or pins 12 may function as a heat sink, or a separate heat sink (e.g., sink 21, FIG. 1) may couple with spreader 16.

[0033] Spring element 18 serves to bias pins 12 in accommodating physical separation differences 32 to relevant pins 12 so as to ensure macroscopic conformity (i.e., where multiple pins conform to an object surface larger than any one pin) between pins 12 and outer surfaces of dies 30. By way of example, spring element 18 biases pins 38 with die 30C, spring element 18 biases pins 40 with die 30B, and spring element 18 biases pins 42 with die 30A. Pins 44 are not engaged with object 30 and are in this example maximally extended from system 10. Other pins 12 – not shown in FIG. 3 – may or may not connect with object 30.

[0034] FIG. 4 shows a cross-sectional view of one thermal interface system 50 of the invention. System 50 is shown with three different pin configurations, one for each of pins 52, 54, 56. Though not required, typically each pin is in a same configuration (e.g., each of pins is in the configuration of pin 52, pin 54 or 56); in addition, only three pins 52, 54, 56 are shown when system 50 generally has many more pins that enable coupling to micro-features of an object 59 (e.g., object 14, FIG. 1). Pins 52, 54, 56 couple with a thermal spreader 58 via a spring pad 60, as shown (other spring elements may augment or replace pad 60, such as described below). In the configuration of pin 52, a head 52A of pin 52 extends from spring pad 60 while a shaft 52B of pin 52 extends at least partially within a passageway 58A of spreader 58. In the configuration of pin 54, a head 54A of pin 54 is coplanar with spring pad 60 while a shaft 54B of pin 54 extends at least partially within a passageway 58B of heat sink 58. In the configuration of pin 56, a head 56A of pin 56 is embedded within spring pad 60 while a shaft 56B of pin 56 extends at least partially within a passageway 58C of heat sink 58. In each pin configuration, the shaft length of the pin 52 is sufficiently long to ensure thermal transfer between the shaft and spreader 58.

[0035] Passageways 58A, 58B, 58C are shown with a closed end 62, though the passageways(s) may extend entirely through spreader 58 as a matter of design choice (e.g., as in FIG. 1). In the configuration of FIG. 4, passageways 58A-58C thus form a cavity 65 within spreader 58. Cavity 65 may itself function as a spring

element. By way of example, air or other thermally conductive medium may fill cavity 65 and compress/expand with pin movement within passageways 58A-58C. A small vent 67 may be included within end 62 as a matter of design choice to vent over-pressurization of material in cavity 65; vent 67 is shown with only one passageway 58A for ease of illustration even though system 50 may include multiple vents 67 as a matter of design choice.

[0036] Each of pins 52, 54, 56 form a gap 64 with an internal surface 66 of respective passageways 58A, 58B, 58C; gap 64 is formed between the smaller diameter of shaft 52B, 54B, 56B within the larger diameter of respective passageways 58A, 58B, 58C. By way of example, each of pin shafts 52B, 54B, 56B may have a cylindrical shape with a diameter of about 0.06 inch, and each passageway 58A, 58B, 58C then has a diameter of between about 0.0605 to 0.065 inch. Gaps 64 (and/or cavities 65) may be filled with thermally conductive grease, gas, air or other thermally conductive medium. Pin shafts 52B, 54B, 56B may also be rectangular in shape; passageways 58A, 58B, 58C accordingly would also be rectangular, though larger in size to accommodate pin movement therein.

[0037] Pins 52, 54, 56 may move with spring element 60. Spring element 60 is for example a thermally conductive sponge-like material, though a non-conductive pad may also be used so long as an aperture cut into the pad permits thermal energy transfer from object 59 to the relevant pin 52. A layer 70 of thermally conductive grease may cover over element 60 and pins 52, 54, 56 to encourage transfer of thermal energy from object 59 to spreader 58; grease 70 is particularly useful in the configurations of pin 52, 54 as spring element 60 can provide thermal microscopic contact between object 59 and pin 56.

[0038] Though not required, system 50 may include a heat sink 71 to draw thermal energy from pins 52 and spreader 58. Thermal grease 73 can improve thermal conductivity between spreader 58 and heat sink 71, as shown. Illustratively, thermal energy 75 from object 59 travels through layer 70, into pins 52, 54, 56, out of pin shafts 52B, 54B, 56B and into spreader 58 through the gap 64 between shafts 52B, 54B, 56B, and into heat sink 71, such as shown.



[0039] The interfaces of FIG. 1 - FIG. 4 take advantage of the physics of thermal resistance, which equals  $L/KA$  (where  $L$  is the path length of heat flow,  $K$  is the conductivity, and  $A$  is the area through which the heat flows). A way to decrease thermal resistance of interfaces 10, 50 is therefore to decrease path length  $L$  or to increase area  $A$ . Since interface 10, 50 is already very close to object 59 from which it dissipates heat,  $L$  is already small; the invention thus has particular advantages in increasing area  $A$ . Area  $A$  is approximately equal to the number of pins forming the interface times the barrel area of the pin shafts forming gap 64. By ensuring gap 64 is small, there is negligible heat resistance across the gap, and spreader 58 maximally dissipates heat from object 59. Increasing the number of pins in interface 50 increases heat transfer efficiency by increasing the cumulative area of gaps 64 between object 59 and spreader 58; this efficiency improves further when gaps 64 are filled with thermally conductive grease or paste. Accordingly, the interfaces of the invention may utilize hundreds, thousands or millions of pins, as a matter of design choice. Pins may also be arranged in any pattern with the spreader, such as shown by the configuration of pins 12, FIG. 2, or pins 82, FIG. 7. The pins are thermally conductive; accordingly, copper, aluminum or other thermally conductive material provides acceptable materials for construction of the pins.

[0040] A thermal pad of the prior art may exhibit a thermal resistance of between about 2-5 inches-squared per Watt per degree C while accommodating surface irregularities of only about 0.06 inch. A prior art thermal pad with a thickness exceeding about 0.002 inch exhibits thermally insulating properties or behaviors compounding the undesirable issues discussed above relative to the prior art. The interfaces 10, 50 of the invention, on the other hand, can for example improve such thermal resistances to at least about 0.2-0.5 inches-squared per Watt per degree C, and further accommodate macroscopic surface variations and differences (e.g., differences 32, FIG. 3) exceeding 0.06 inch.

[0041] FIG. 5 shows a top view of one thermal interface system 80 of the invention; FIG. 6 shows a cross-sectional view of system 80; and FIG. 7 shows a perspective view of system 80. A plurality of pins 82 conform to a surface of an

object 83 (e.g., object 14, FIG. 1) so as to dissipate heat from object 83 to a thermal spreader 84. Each of pins 82 has a shaft 85 within respective passageways 87 of spreader 84; sizing of pins 82 within passageways 87 forms a small gap 86 between each pin 82 and spreader 84. Gap 86 may be filled with thermally conductive material such as grease. In one acceptable configuration of system 80, a dimension 88 is 6mm, a dimension 90 is 6.5mm, a dimension 92 is 0.86mm, a dimension 94 is 2.1mm, a dimension 96 is 25.4mm, a dimension 98 is 1.35mm, a diameter 100 of each of pins 82 is 0.084mm, a dimension 102 is 1.70mm, and a pin length dimension 104 is 1.52mm. For purposes of clarity, a spring element is not shown in FIG. 5 and FIG. 6; however a spring element such as spring element 60, FIG. 4, may for example be included with system 80 within the space provided by dimension 92. Helical springs such as shown in FIG. 9 or FIG. 10 may also be used.

[0042] FIG. 8 illustrates how two or more systems 80 may for example dissipate heat from multiple semiconductor packages 81 of a printed circuit board 110. As shown, three thermal interface systems 80 couple to packages 81 to dissipate heat generated thereby. Each package 81 may include a die (85, FIG. 9) that is typically smaller in surface area than each of systems 80. That is, each package 81 may be larger than system 80 as a matter of design choice; generally, however, each system 80 at least covers the surface area of die 85 within package 81. As described in more detail below, a common heat sink 83 may couple with multiple systems 80, as shown, to dissipate heat from spreaders 84.

[0043] FIG. 9 shows a cross-sectional side view of two thermal interface systems 80 coupled with two packages 81; a semiconductor die 85 is within each package 81, as shown. Pins 82 move within spreaders 84 to accommodate the height differences 93 of packages 81; accordingly, common heat sink 83 may couple to a substantially flat plane 101 along the top of spreaders 84. Thermal grease at plane 101 between spreaders 84 and heat sink 83 facilitate thermal communication therebetween.

[0044] Those skilled in the art should appreciate that changes may be made to the above description without departing from the scope of the invention. By way of

example, spring elements 18, 60 may be replaced, or augmented by tiny springs disposed within passageways 16A, 58A, 58B, 58C so as to outwardly push pins outward from heat sink 16, 58, 84 in conforming to a heat generating object 14, 30, 59, 83. A configuration such as this is shown in FIG. 10. FIG. 10 specifically illustrates one thermal interface system 150 of the invention that incorporates a plurality of spring elements 152 disposed with passageways 154 of a thermal spreader 156 to bias pins 158 outwardly (along direction 159) from spreader 156 to conform to an object 160. Elements 152 couple with spreader 156 and pins 158 via connectors 162 so that pins 158 appropriately bias against object 160 to collectively conform to surface 160A by appropriate compression against spreader 156.

[0045] Spring elements may also be utilized underneath the heads of the pins, and between the heads and the spreader, as shown in the thermal interface system 161 of FIG. 11. Three pins 162A-162C are shown in FIG. 11. A plurality of springs 164 generate compressive forces to bias pins 162 along direction 166, as shown, for thermal communication with an uneven object 168; springs 164 compress between spreader 172 (or against element 176 described below) and pin head 163 to accommodate the uneven surface of object 168. Like above, pins 162 move along direction 166 and within a like plurality of passageways 170 of a thermal spreader 172. A heat sink 174 may optionally couple to spreader 172 to facilitate cooling of object 168.

[0046] FIG. 11 also illustrates one pin embodiment of a thermal interface system to retain pins 162 relative to spreader 172. In this embodiment, a retaining element 176 couples with spreader 172. Pins 162 are shown with a shoulder 178 that abuts element 176 when extended as in pin 162A; element 176 forms apertures to accommodate passage of the above-shoulder extensions 180 of pins 162. Accordingly, the retaining embodiment of FIG. 11 ensures that pins 162 do not completely separate from spreader 172.

[0047] Since certain changes may be made in the above methods and systems without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawing be

interpreted as illustrative and not in a limiting sense. It is also to be understood that the following claims are to cover all generic and specific features of the invention described herein, and all statements of the scope of the invention which, as a matter of language, might be said to fall there between.

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